The Absolute Radiance Interferometer (ARI) for the UW/LASP/GSFC CLARREO Tech Demo/Pathfinder on ISS

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CLARREO Science Definition Team Meeting
NASA LaRC, 28-30 Oct 2014

UW/LASP/GSFC CLARREO Tech Demo/Pathfinder on ISS

A low cost mission to kickoff CLARREO and provide Risk Reduction

Summary of Events

•**CLARREO SDT (7-9 January):** Steve Volz, NASA Headquarters, indicated that there was a chance of funding a low cost International Space Station (ISS) mission similar to those defined in an earlier ISS-DS-ESM Cross-Mission Study solicited from his office

•**GSFC Meeting (31 January):** LaRC and GSFC Center directors endorsed CLARREO team pushing for a low cost Tech Demo using ESTO developed instruments

•**International TOVS Study Conference (ITSC-19, 26 March-1 April):** The working groups strongly recommended an ISS Pathfinder (see following viewgraphs)

•**Volz Meeting (23 July):** Bruce Wielicki presented the Tech Demo concept based on inputs from UW, LASP, and GSFC—more time/cost phasing information was requested

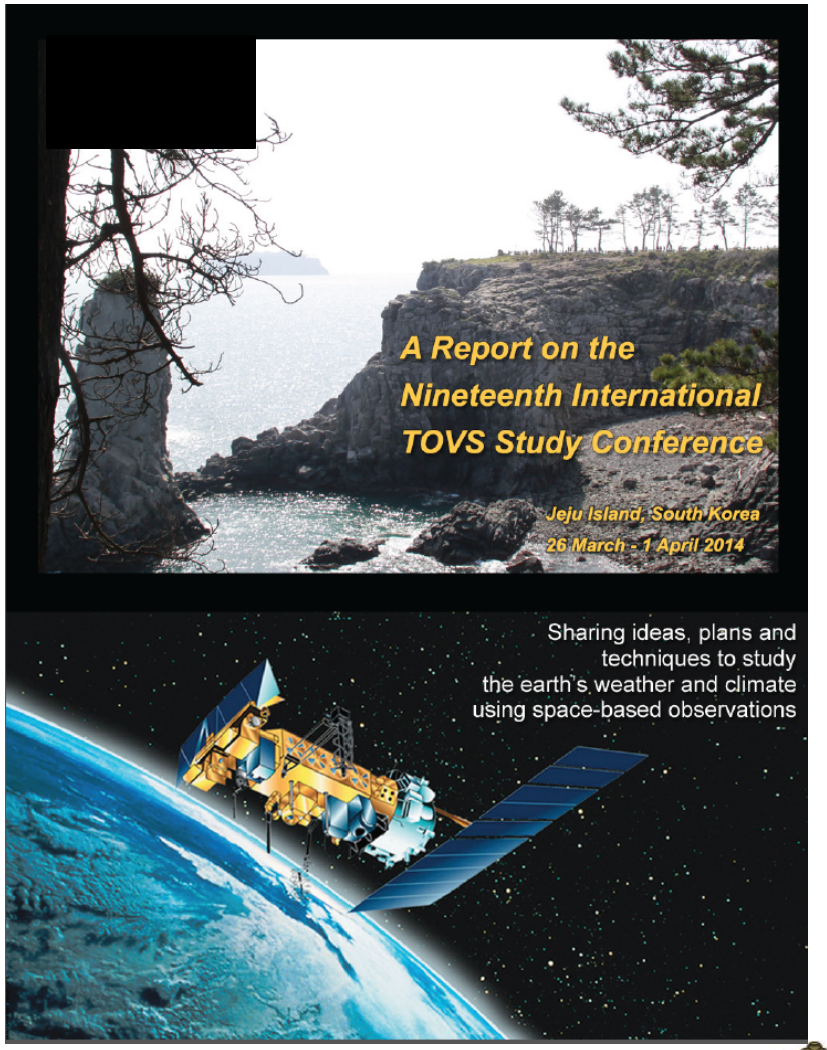
•**Volz Moving to NOAA (29 September):** Announcement that Steve Volz will lead NOAA's Satellite and Information Service (NESDIS) starting 2 November

•**The Climate Symposium (13-17 October):** Mike Freilich as well as Jack Kaye participated extensively and Bruce Wielicki and myself promoted the Tech Demo/ Pathfinder Concept and I briefed Freilich on the ARI IR Pathfinder instrument

International TOVS Working Groups Strongly Recommend Pathfinder on ISS

1.2 SUMMARY OF MAJOR CONCLUSIONS*

6. To satellite agencies: noting that absolute calibration with on-orbit SI traceability is critical for significantly reducing uncertainties in monitoring climate trends, ITWG recommends to pursue the realization of absolute calibration missions (such as CLARREO), including considering flight opportunities on the International Space Station



** p3 of International TOVS Study Conference (ITSC-19) final working group report*

Specific Working Group Recommendations from ITSC-19 report (1)

International Issues and Future Systems Working Group

Global Design of the GOS, implementation and continuity issues:
Calibration reference standard

•As part of GOS design, a reference payload such as CLARREO would (i) provide an in-orbit calibration reference and (ii) provide ultimately a climate benchmark. A pathfinder mission on the ISS is a good step in this direction that will improve the value of currently operated or planned sounders. Noting that the accuracy of IASI, CrIS is estimated at the order of 0.2K, reducing the uncertainty would reduce the time (number of decades) necessary to assess climate trends. The ITWG recommends such a mission, and encourages the community to then participate in testing and exploiting the results.

Climate Working Group —Cal/Val Activities

•Truth from space is urgently needed for generating climate quality datasets. Access to absolute calibration (wrt SI) in the IR (and Vis) is possible thanks to the state of the art technology like the one developed for CLARREO mission. With the postponement of the CLARREO absolute calibration mission, flying CLARREO type instruments on the ISS is imperative. The group strongly supports such missions also including solar and RO.

Specific Working Group Recommendations from ITSC-19 report (2)

- **Recommendation Climate-8:** The realization of absolute calibration missions (such as CLARREO) is further supported including flight opportunities on the ISS.
- **Action Climate-8:** ITWG Co-Chairs to communicate (above) to CGMS.

Advanced Sounders Working Group

SI Traceable Reference Instruments for improved climate observatories

- The AS working group believes that the advent of advanced climate observatories to benchmark the Earth's climate (using spectrally resolved IR and reflected solar radiances plus GPS radio-occultations like the NASA Tier 1 CLARREO Mission) could be used to cross-calibrate operational sounding instruments to SI-traceable standards which would increase their value for quantifying the climate state and decadal trends.

- **Recommendation AS-9 to space agencies:** Develop, test, and implement an SI Traceable radiometric standard in space as soon as feasible. Particularly, the ASWG encourages early pathfinder demonstrations of new technologies for referencing these measurements to International Standards on-orbit. As a specific example, an International Space Station flight of the new technologies developed for CLARREO with NASA Earth Science Technology Office (ESTO) support would be especially valuable for furthering a full-up mission.

Why Fly the ARI on ISS now?

The Short answer is that the Absolute Radiance Interferometer (ARI) on ISS will provide, not only a tech demo for CLARREO cost and technical risk reduction, but also the start of an accurate climate benchmark, identified as critically important in the 2007 Decadal Survey.

The key components supporting the above are

•ARI has demonstrated the ability to fully meet the CLARREO 0.1 K 3-sigma measurement accuracy requirement over the required spectral range, including the Far IR out to 50 microns.

•Sampling requirements for establishing an initial benchmark (unbiased temporal and spatial sampling) are met by ISS below 52 degrees latitude.

•Via Intercalibration of the AIRS (on EOS Aqua) and CrIS (on Suomi NPP) at 0130/1330 local times, IASI (on EUMETSAT MetOp A and B) at 0930/2130 local times, and likely the Chinese sounder on (FY3E) at 0530/1730, reasonable sampling can be extended to high latitudes for all but the Far IR portion of the spectrum.

•ARI has no fundamental life limiting components, and with ISS life extended until 2024 has a good chance of creating the 5 year record needed for a credible benchmark.
To make use of this opportunity, the project clearly needs to be started soon.

Absolute Radiance Interferometer (ARI)

Selected Slides from 2014 Presentations at

- **AMS, Atlanta, 5 February**
- **IGARSS, Quebec, 15 July**
- **The Climate Symposium, Darmstadt, Germany, 13 October (Poster)**
- **SPIE Asia Pacific Remote Sensing, Beijing, 16 October**

Earth Radiation Budget, *the old way*

13 Oct 1959-Feb 1960 Explorer 7

The 1st meteorological satellite instrument to observe the Earth

- Radiometer designed by Verner Suomi & Robert Parent
- Omni-directional spheres
- 3-color (black, white, gold)

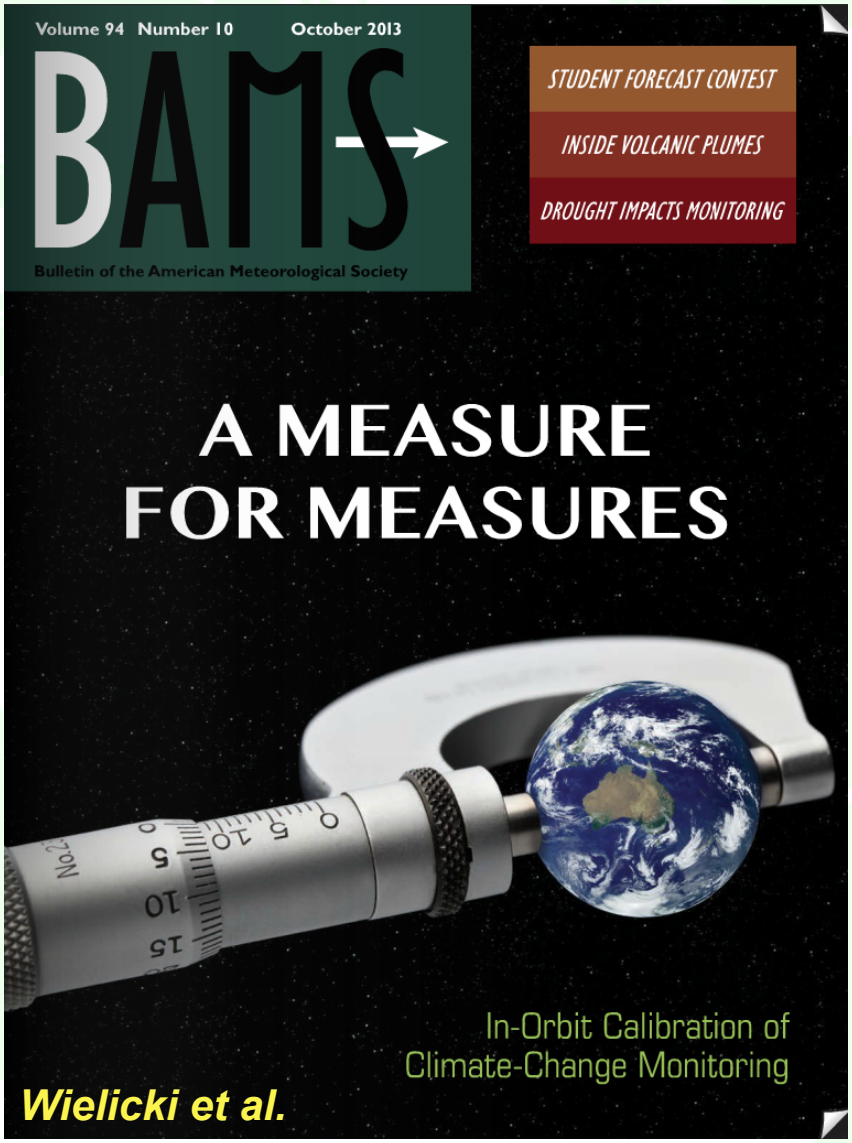
Spectrally integrated obs continue today

An outgrowth of measuring the energy budget of a corn field

NASA just in its 2nd year

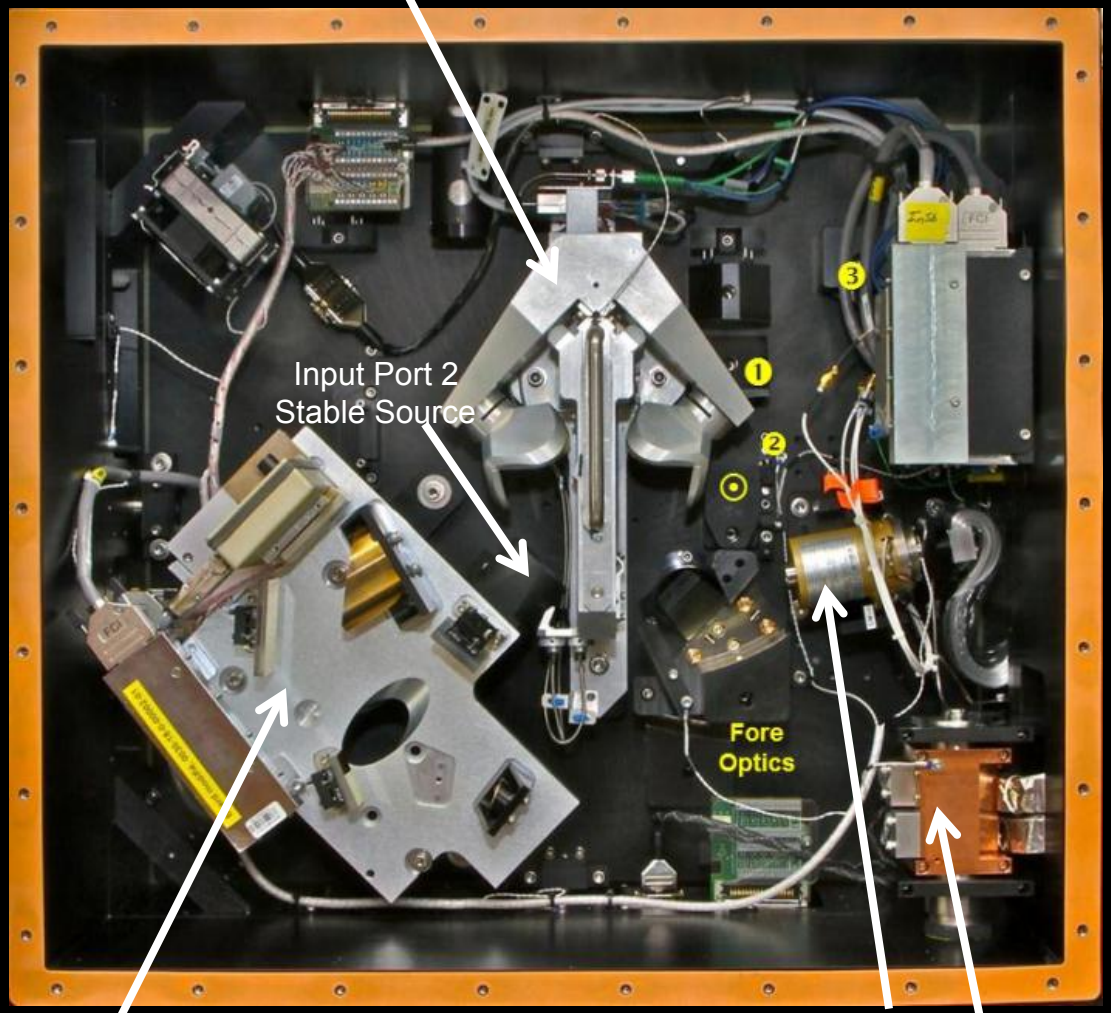
Introduction to CLARREO and ARI

- **CLARREO** (Climate Absolute Radiance & Refractivity Observatory)
  a 2007 Decadal Survey Tier 1 mission
  - IR & Reflected Solar spectra coupled with GPS occultation data offer unprecedented accuracy to provide much higher climate change sensitivity than existing climate records
    (from total integrated IR & Solar data)
  - Metrology lab on-orbit serves as "NIST in orbit"
- **CLARREO** to Benchmark the Earth's climate
  - Analogous to marking a glacier's current extent
- **CLARREO** to be an Inter-calibration Standard
  - GSICS (Global Space-based Inter-Cal System)
  - e.g. Greatly enhancing the value of the climate record from high spectral resolution IR sounders starting in 2002 (AIRS, IASI, CrIS)
- **Absolute Radiance Interferometer (ARI)**
  is an IR prototype instrument with new on-orbit verification technology ready for CLARREO or a pathfinder mission



Absolute Radiance Interferometer (ARI) Prototype

with a short upgrade path to flight



Calibrated FTS

- Corner-cube interferometer used in 4-port to avoid double pass; Strong flight heritage
  - 0.5 cm^{-1} resolution (±1 cm OPD)
  - 1.55 μm diode laser for interferogram sample control & fringe counting
  - 10 cm CsI single-substrate beamsplitter
- Fore optics designed to
  - minimize polarization effects
  - minimize sizes of calibration/ verification BBs & reflectivity sources
  - minimize stray light by providing effective field and aperture stops
  - maximize energy throughput
- 3-50 μm Spectral Coverage
  - Highly linear pyroelectric detector, all reflective aft optics: 10-50 μm
  - Cryo-cooler for MCT & InSb semi-conductor detectors: 3-18 μm

Absolute Radiance Interferometer (ARI) Prototype

with a short upgrade path to flight

On-orbit Verification and Test System (OVTS) Technologies

❶ On-orbit Absolute Radiance Standard (OARS) cavity blackbody using three miniature phase change cells to establish the temperature scale from -40, to +30 C to better than 10 mK

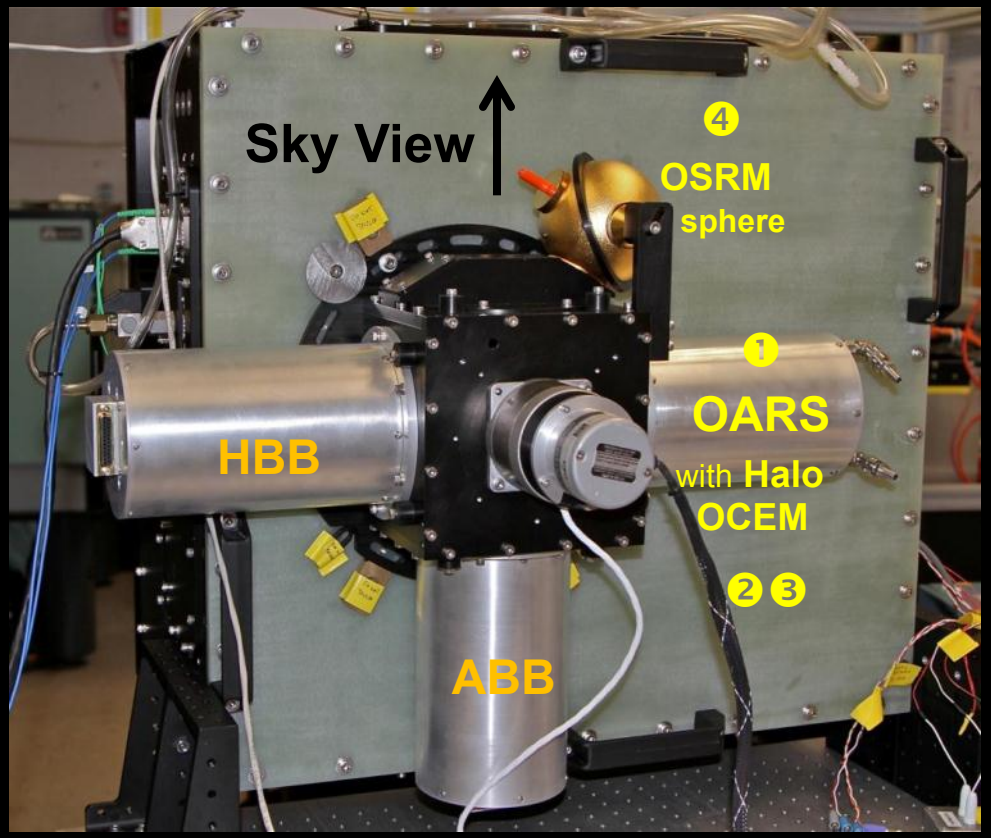
❷ On-orbit Cavity Emissivity Module (OCEM) using Heated Halo source allowing the FTS to measure the broadband spectral emissivity of the OARS to better than 0.001

❸ OCEM-QCL* using a Quantum Cascade Laser source to monitor changes in the mono-chromatic cavity emissivity of the OARS & Cal BB to better than 0.001

❹ On-orbit Spectral Response Module* (OSRM) QCL used to measure the FTS instrument line shape

** QCL functions demonsttated separately*

OVTS Sources

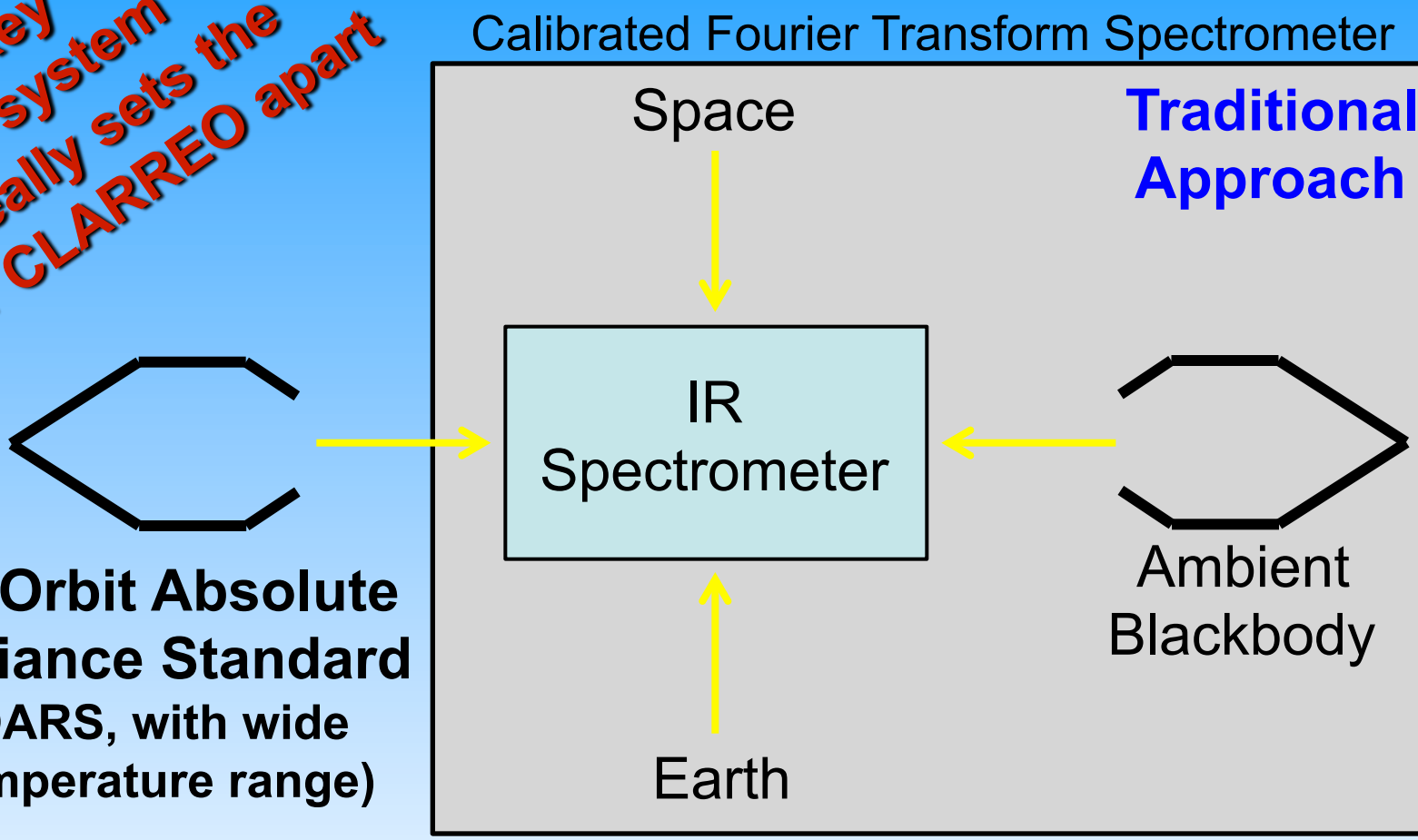


Calibrated FTS Blackbodies (HBB & ABB)

All components at flight scale

On-Orbit Verification and Test System

A key new system that really sets the ARI for CLARREO apart



On-Orbit Absolute Radiance Standard
(OARS, with wide Temperature range)

OVTS Provides On-Orbit, End-to-End Calibration Verification & Testing Traceable to Recognized SI Standards

On-orbit Absolute Radiance Standard OARS

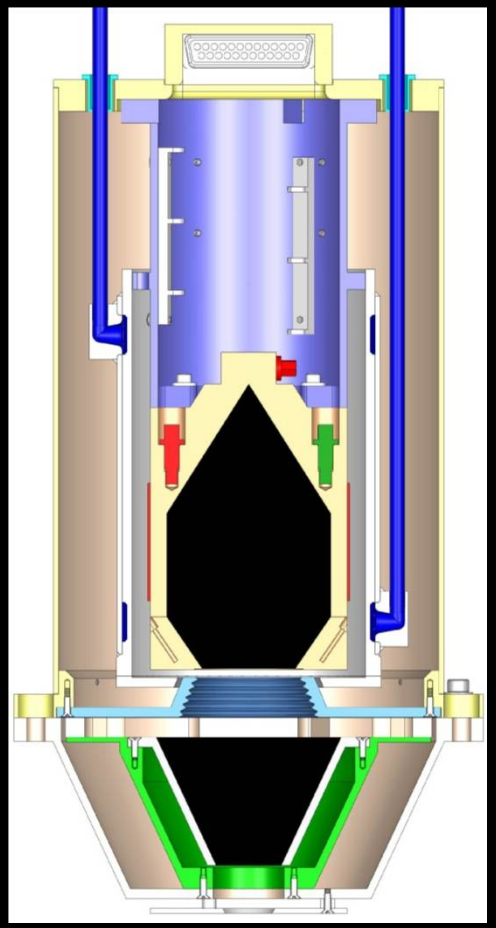
Phase
Change
Cell

Heated Halo
& Halo Insulator

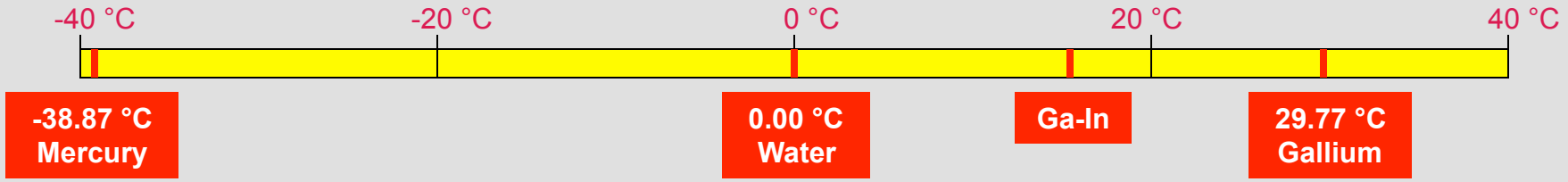
Cavity

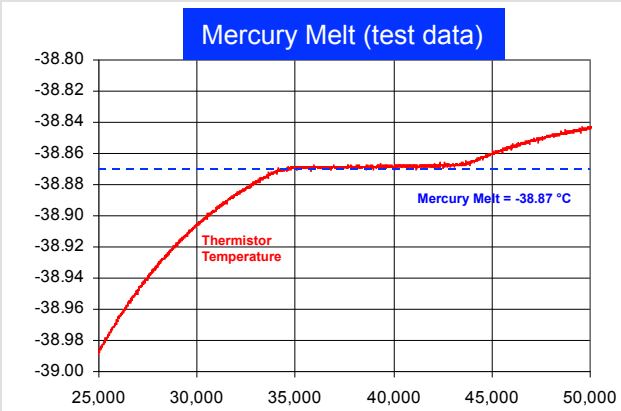
Inner Shield
& Isolator

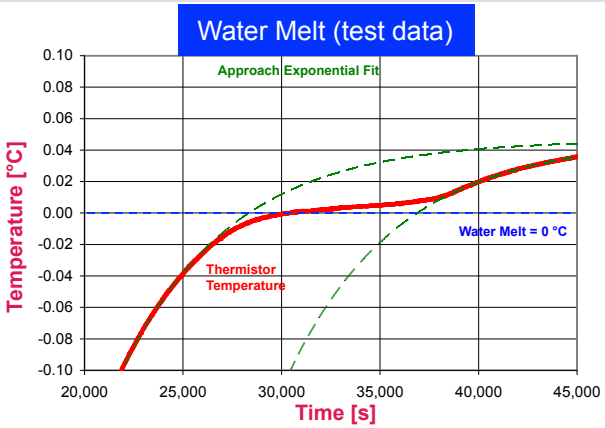
Assembly Diagram

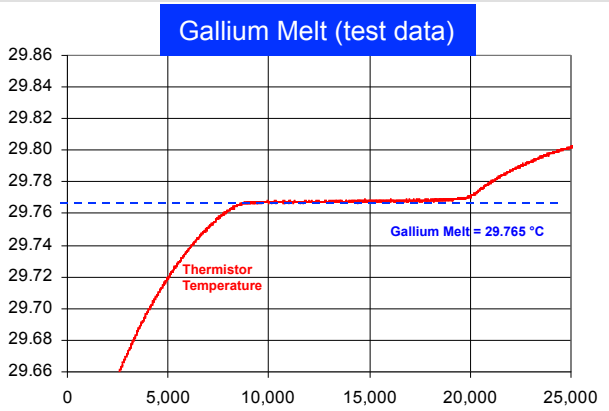


Temperature Scale Established to < 10 mK on-orbit

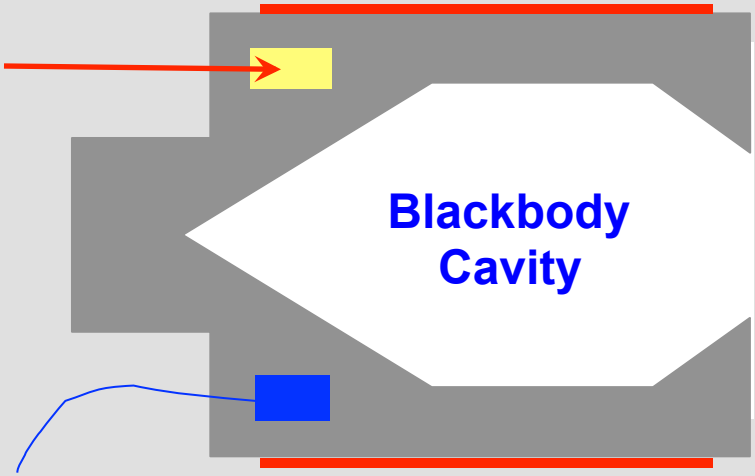








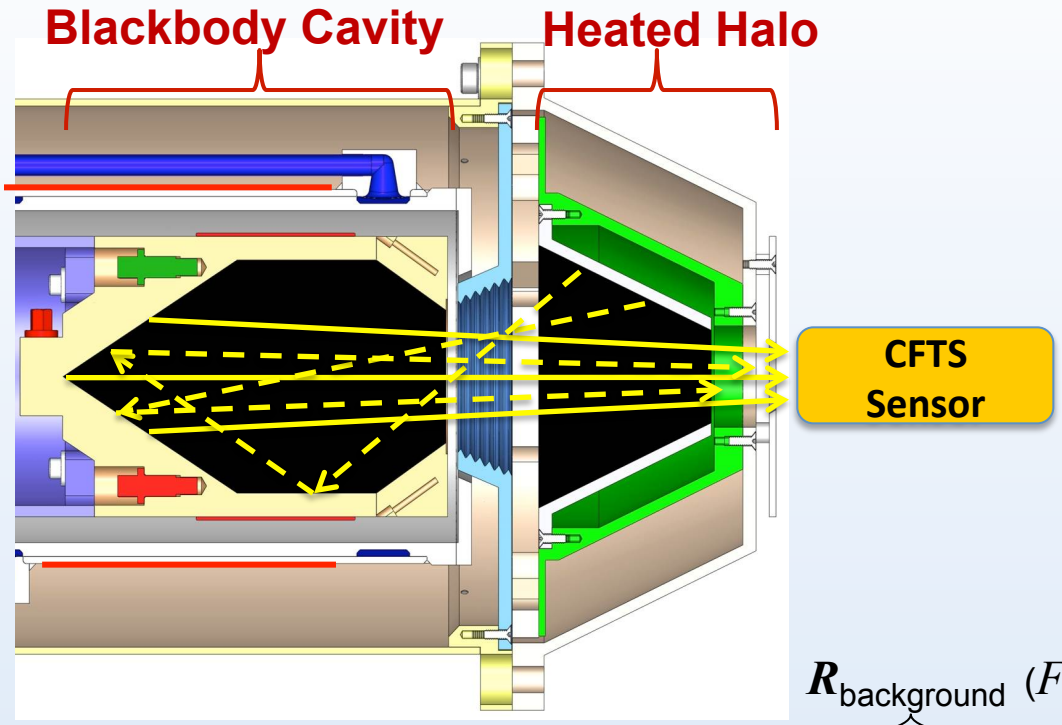
Phase Change Cell (Ga, H_2O, or Hg)



Thermistor (plotted above)

Plateaus (shown in plots) provide known temperatures to better than 5 mK

Heated Halo Concept



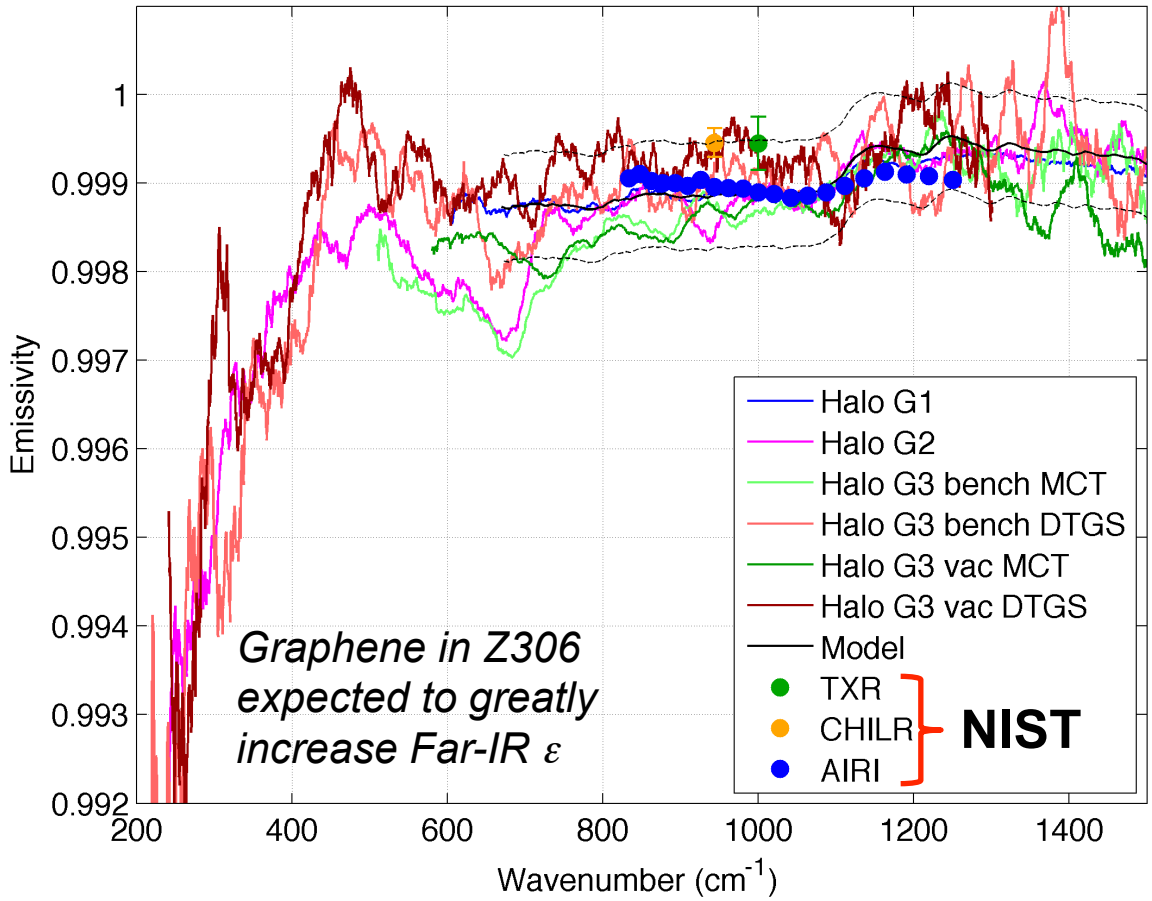
$R_{background}$ (F=fractional view to Halo)

$$R_{scene} = \varepsilon \bullet B(T_{BB}) + (1-\varepsilon) \bullet [F \bullet B(T_{Halo}) + (1-F) \bullet B(T_{room})]$$

Radiance emitted from BB ***Background Radiance Reflected from BB***

$$\left\langle 1 - \varepsilon_{\tilde{\nu}}(t) \right\rangle_t = \left\langle \frac{R_{scene}(t) - B[T_{BB}(t)]}{R_{background}(t) - B[T_{BB}(t)]} \right\rangle_t$$

Blackbody Emissivity Measured to < 0.001 on-orbit

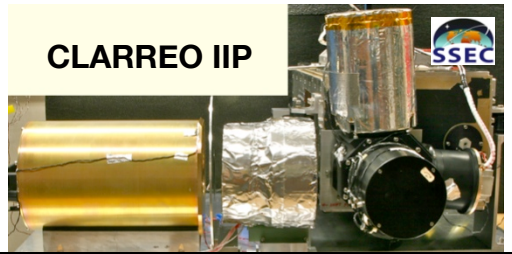


3-σ emissivity of 0.0006 uncertainty indicated by dashed lines applied to model

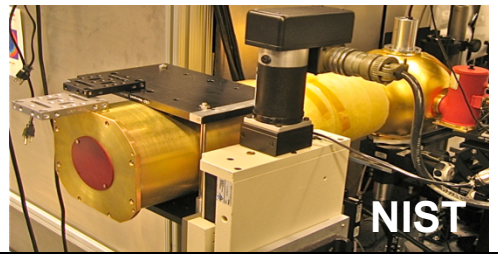
Good agreement with NIST measurements

Far IR tests with Graphene in Z306 are in progress

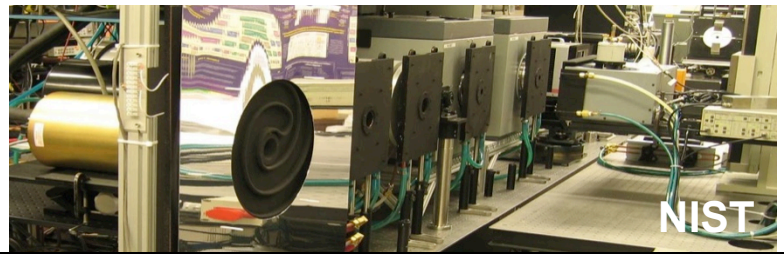
UW Heated Halo



NIST CHILR



NIST AIRI



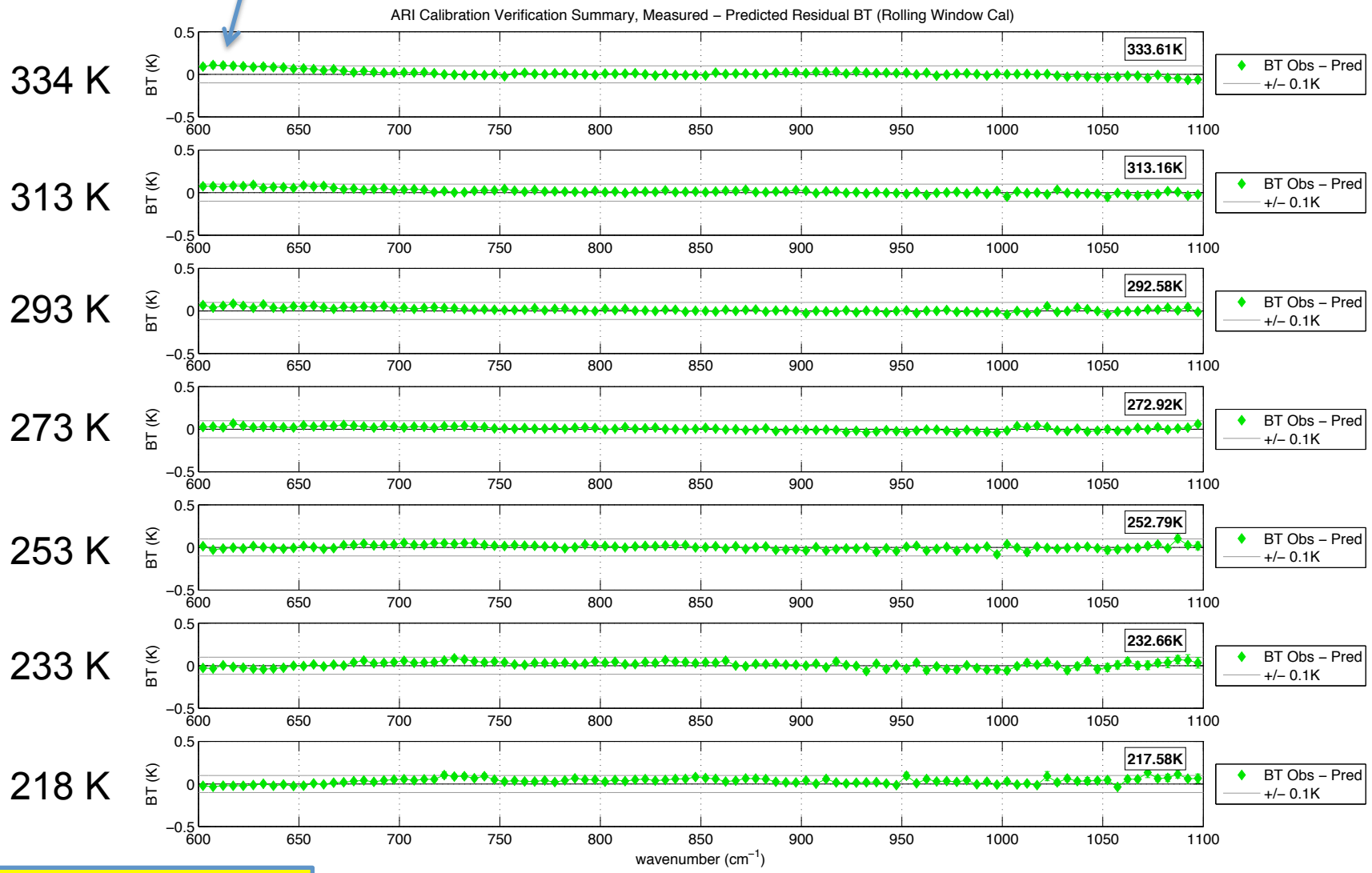
Brightness Temperature Accuracy Verified to < 0.1 K

(CFTS calibrated - OARS verification)

MCT

Correction of field stop problem removes this error

Error bars only include statistical error in measurement



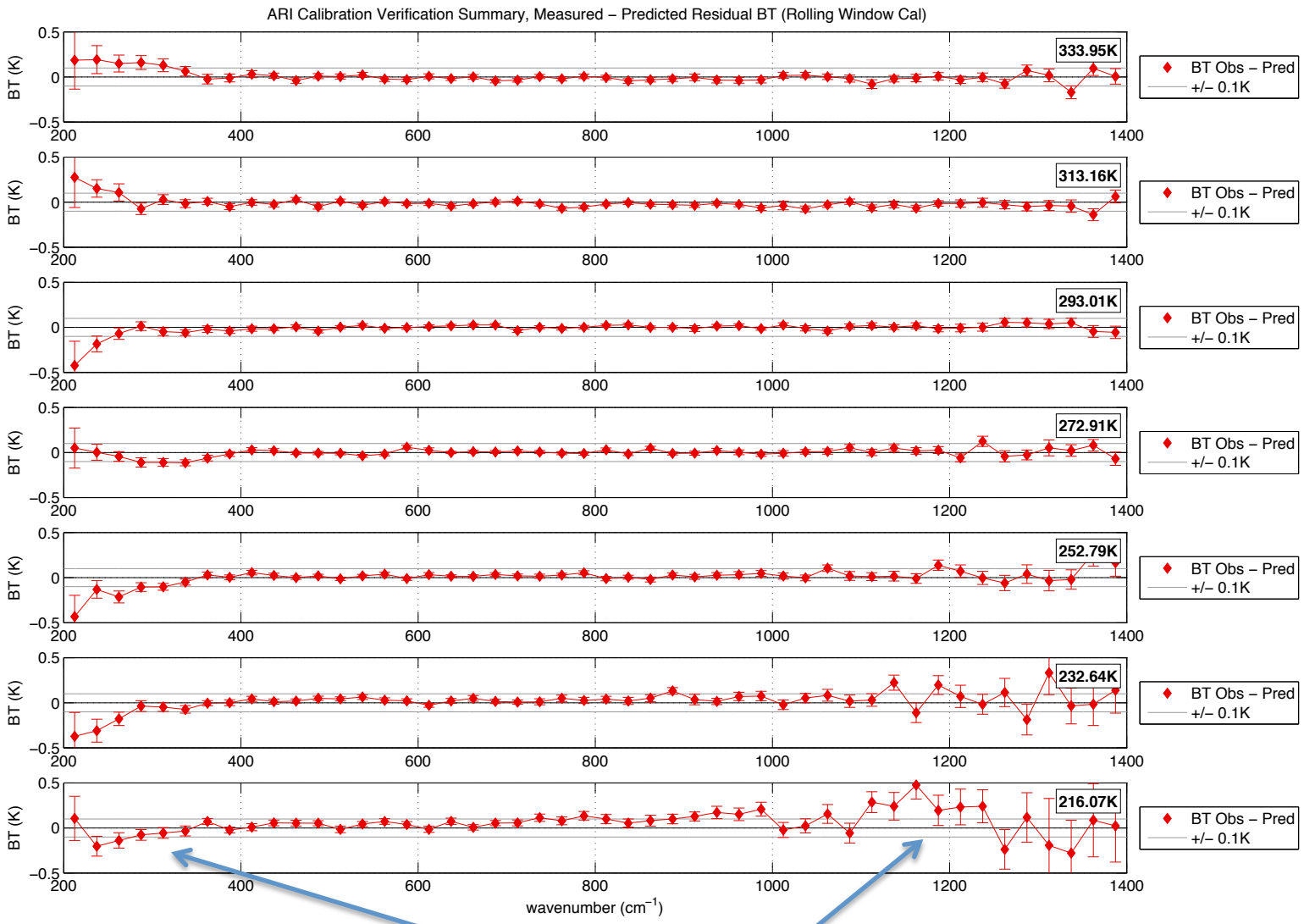
Spectral Averaging Bin Width is 5 cm^{-1}

Brightness Temperature Accuracy Verified to < 0.1 K

(CFTS calibrated - OARS verification)

DTGS

Error bars only include statistical error in measurement

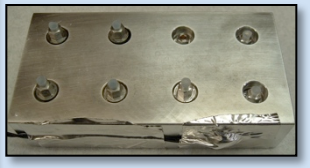


Spectral Averaging Bin Width is 25 cm^{-1}

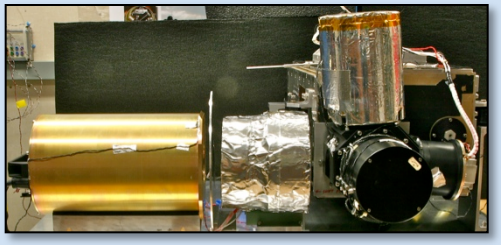
Bin averaged result subject to low SNR at band edges

ARI Technology Development

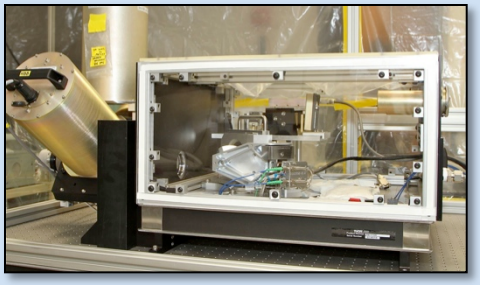
Miniature Phase Change Cell (MPCC)



MPCC Component Integration, Characterization and Accelerated Life Testing

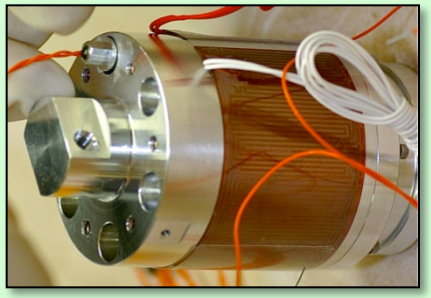


Heated Halo Generation-1 (Breadboard Halo, AERI BB with Scanning HIS Aircraft FTIR)

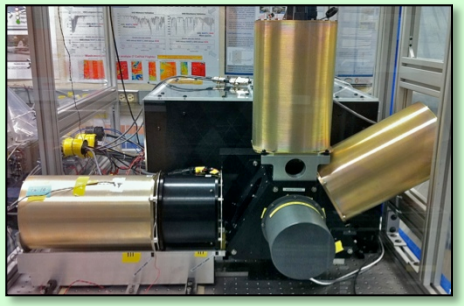


Absolute Radiance Interferometer (ARI) Breadboard

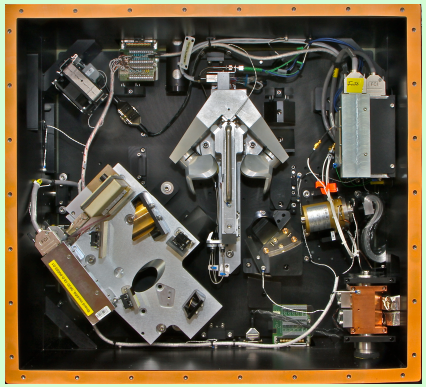
TRL 4



Integration of MPCC into Breadboard Blackbody for Thermal Testing

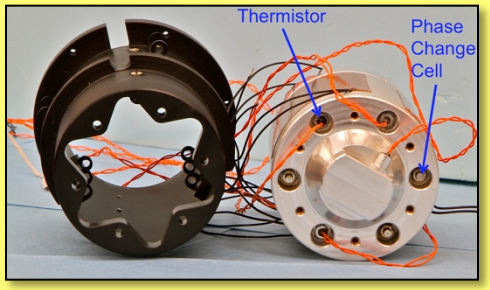


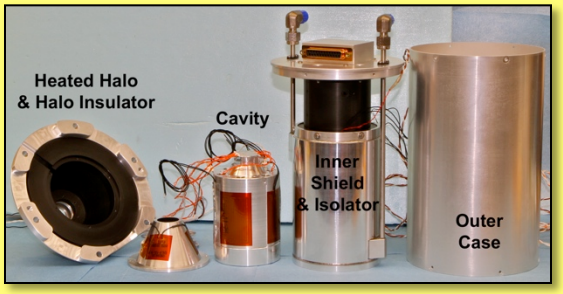
Heated Halo Generation-2 (Large Conical Halo, AERI BB with ARI Breadboard FTIR)



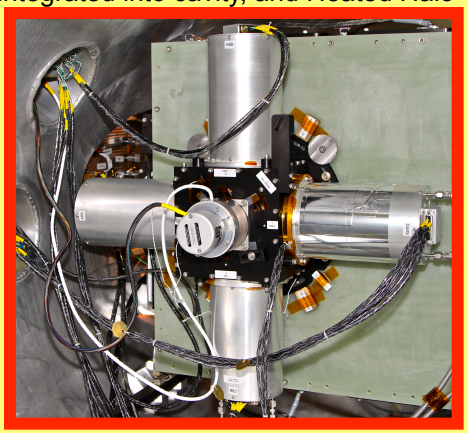
Absolute Radiance Interferometer Prototype

TRL 5





On-Orbit Absolute Radiance Standard: New 30 mm Aperture BB with MPCC integrated into cavity, and Heated Halo



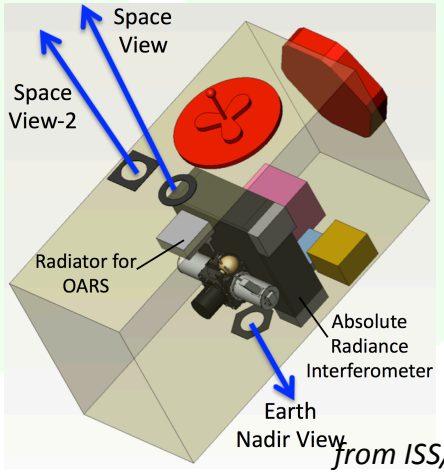
ARI Prototype Tested in Vacuum

TRL 6

Ready for Flight Program

ARI for CLARREO Pathfinder Mission

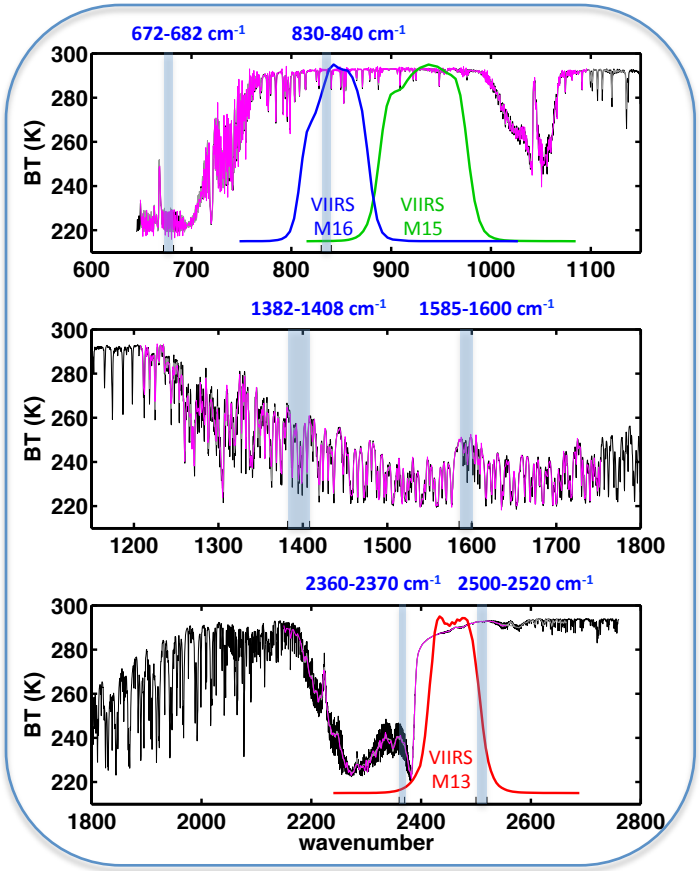
- **Vacuum Testing of CLARREO Flight Prototype *Absolute Radiance Interferometer (ARI)* has demonstrated 0.1 K 3-sigma performance of the**
  (1) Calibrated FTS (CFTS) and
  (2) On-orbit Verification and Test System (OVTS), bringing the full ARI system to TRL 6
- **The next step should leverage NASA ESTO's investment with a spaceborne demonstration as a CLARREO IR pathfinder. Flight on the International Space Station (ISS) is being considered.**



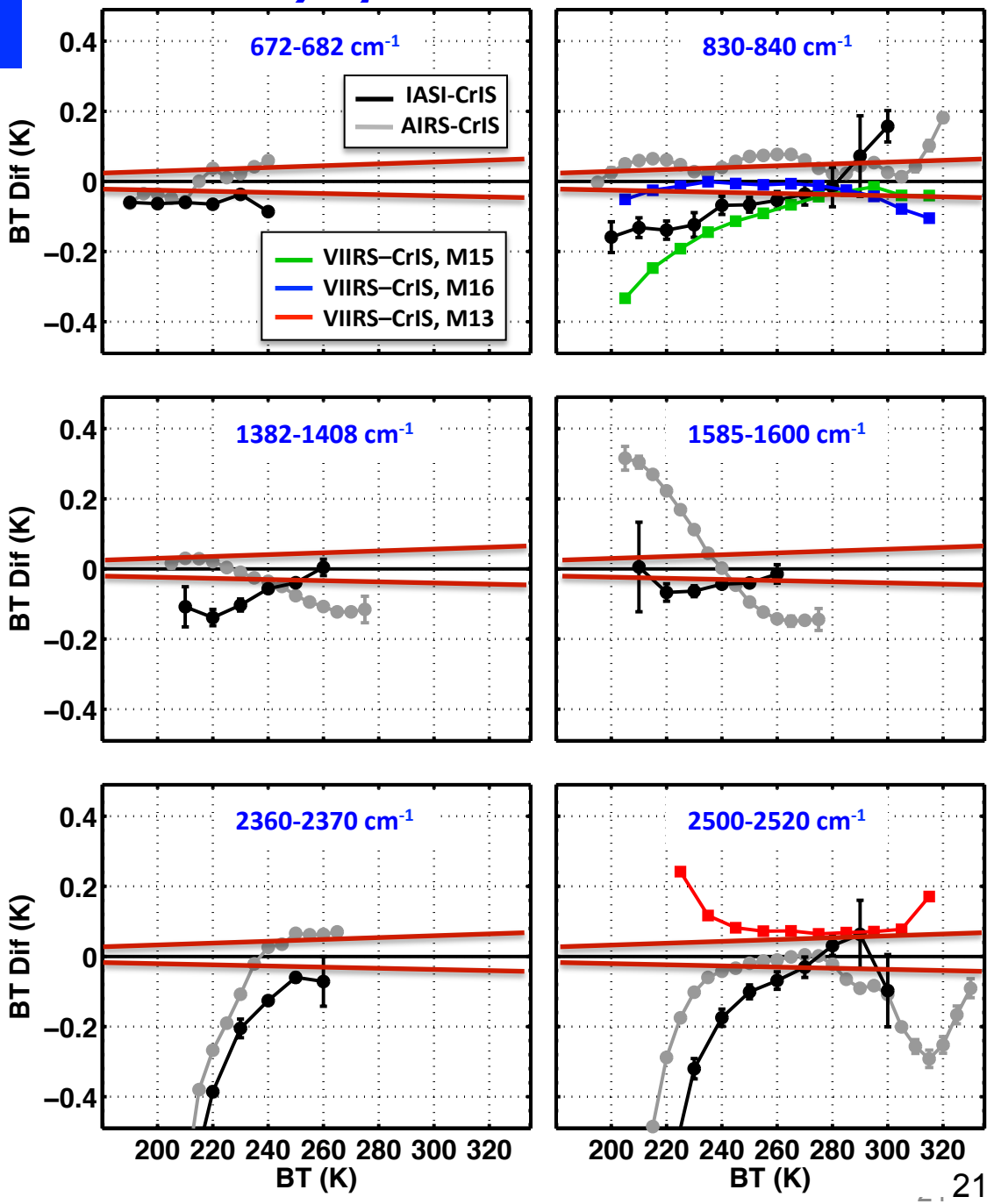
JEM-EF EFU Site #4
from ISS/DS/ESM Cross Mission Study

Pathfinder Mission Offers Valuable On-orbit Standard

- **ARI not-to-exceed Uncertainty provides better "truth"**
- **Residual from CrIS for:**
  - AIRS
  - IASI
  - VIIRS: M13, M15, M16

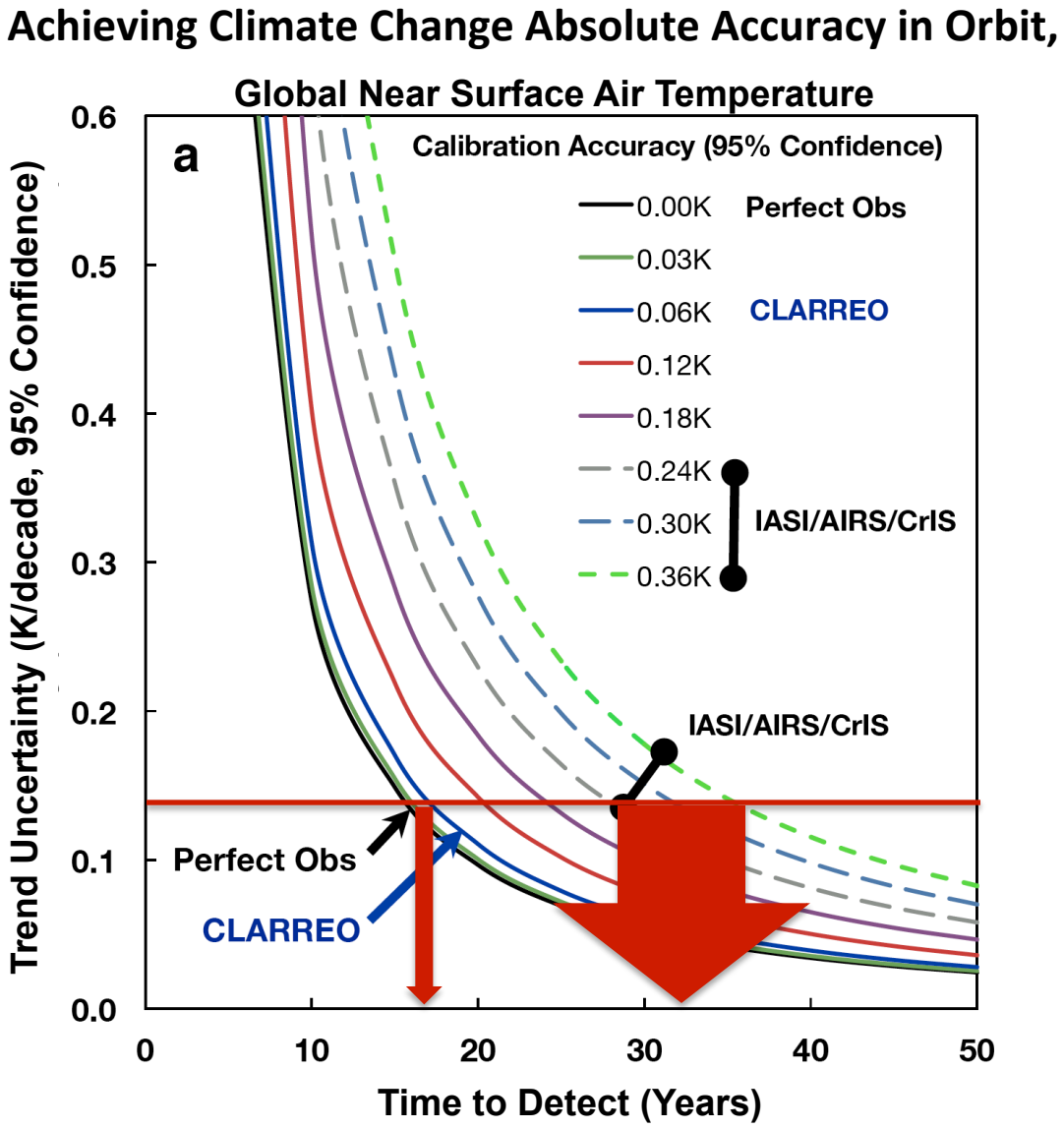


Summary of recent Inter-calibrations



ARI Accuracy Offers Substantially Reduced Time to Detect Global Climate Change

Example with ~ factor of 2 shorter Time to Detect



Wielicki et al., BAMS, 2013

Summary of ARI Status

- **CLARREO:** Efforts of the NASA Science Definition Team have documented compelling science and societal benefits from Benchmarking the Climate State and Inter-calibrating other Satellite Sensors (Wielicki, et al., 2013)
- **CLARREO IR Flight Prototype, ARI:** Recent UW Vacuum Testing combined with prior UW/Harvard IIP technology developments and test results demonstrate capability to meet CLARREO mission performance requirements
- **ARI Technical Readiness:** NASA Earth Science Technology Office (ESTO) has assigned a Technical Readiness Level of 6 supporting readiness for a flight mission
- **International Space station:** ISS offers an attractive and economical avenue to a CLARREO pathfinder mission, especially given the recent ISS lifetime extension until 2024
- **CLARREO pathfinder on ISS:** Would provide economical risk reduction for the full CLARREO mission and a chance to improve the overall accuracy of operational environmental satellite capabilities and leverage them to start a global benchmark record